

AMENDMENTS TO THE SPECIFICATION

Please replace the respective paragraphs of the specification with the following amendment paragraphs:

[0005] The preferred resistance-variable material received between the electrodes typically comprises a chalcogenide material having metal ions diffused therein. A specific example is germanium selenide ($\text{Ge}_x\text{Se}_{1-x}$) ($\text{Ge}_x\text{Se}_{100-x}$) diffused with silver (Ag) ions. One method of diffusing the silver ions into the germanium selenide material is to initially evaporate the germanium selenide glass and then deposit a thin layer of silver upon the glass, for example by sputtering, physical vapor deposition, or other known technique in the art. The layer of silver is irradiated, preferably with electromagnetic energy at a wavelength less than 600 nanometers, so that the energy passes through the silver and to the silver/glass interface, to break a chalcogenide bond of the chalcogenide material. As a result, the glass is doped with silver. If, however, too much silver is doped into the chalcogenide material, the chalcogenide material changes from an amorphous state to a crystalline one and, consequently, the operation of the programmable memory cell is adversely affected.

[0009] According to an exemplary embodiment of the present invention, germanium selenide glasses for use as memory elements are selected from a range of germanium selenide glasses having stoichiometries that fall within a first stoichiometric range R₁ including Ge₁₈Se₈₂ (with a maximum atomic percentage of Ag when doped of about 30% or less) continuously to Ge₂₈Se₇₂ (with a maximum atomic percentage of Ag

when doped of about 20% or less) and which have the general formula $(Ge_{x_1}Se_{1-x_1})_{1-y_1}Ag_{y_1}$ $(Ge_{x_1}Se_{100-x_1})_{100-y_1}Ag_{y_1}$, wherein $18 \leq x_1 \leq 28$ and wherein y_1 represents the fit silver (Ag) atomic percentage which is the maximum amount which will keep the glass in the glass forming region. Typically, y_1 is less than or equal to that which approximately satisfies equation (1):

$$y_1 = 19 + 15 * \sin[0.217*x_1 + 3.23] \dots \dots \dots \quad (1)$$

[0010] According to another embodiment of the present invention, germanium selenide glasses for memory elements are selected from a range of germanium-selenide glasses having stoichiometries that fall within a second stoichiometric range R_2 of doped chalcogenide glasses including $Ge_{39}Se_{61}$ (with a maximum atomic percentage of Ag when doped of about 20% or less) continuously to $Ge_{42}Se_{58}$ (with a maximum atomic percentage of Ag when doped of about 15% or less) and which have the general formula $(Ge_{x_2}Se_{1-x_2})_{1-y_2}Ag_{y_2}$ $(Ge_{x_2}Se_{100-x_2})_{100-y_2}Ag_{y_2}$, wherein $39 \leq x_2 \leq 42$ and wherein y_2 represents the fit silver (Ag) atomic percentage which is the maximum amount which will keep the glass in the glass forming region. Typically, y_1 is less than or equal to that which approximately satisfies equation (2):

$$y_2 = 21 - 11.5 * \exp[-(\ln(x_2/44.4) / (0.84)^2)] \dots \dots \dots \quad (2)$$

[0013] Figure 1 illustrates a ternary phase diagram showing glass forming regions for $(Ge_xSe_{1-x})_{1-y}Ag_y$ $(Ge_xSe_{100-x})_{100-y}Ag_y$ compounds.

[0028] Referring to the drawings, where like elements are designated by like reference numerals, Figure 1 illustrates a ternary phase diagram 200 showing glass forming regions for $(\text{Ge}_{x}\text{Se}_{1-x})_{1-y}\text{Ag}_y$, $(\text{Ge}_{x}\text{Se}_{100-x})_{100-y}\text{Ag}_y$ compounds (i.e., regions in the phase diagram where $(\text{Ge}_{x}\text{Se}_{1-x})_{1-y}\text{Ag}_y$, $(\text{Ge}_{x}\text{Se}_{100-x})_{100-y}\text{Ag}_y$ compounds exist in the glass phase), as studied by Mitkova et al. in *Dual Chemical Role of Ag as an Additive in Chalcogenide Glasses*, Phys. Rev. Letters, Vol. 83, No 19 (Nov. 1999), the disclosure of which is incorporated by reference herein. According to Mitkova et al. and as shown in Figure 1, ternary $(\text{Ge}_{x}\text{Se}_{1-x})_{1-y}\text{Ag}_y$, $(\text{Ge}_{x}\text{Se}_{100-x})_{100-y}\text{Ag}_y$ glasses which comprise germanium selenide glasses with silver (Ag) as an additive form in two distinct compositional regions: a selenium-rich region labeled region I (Figure 1) and a germanium-rich region labeled region II (Figure 1). As also shown in Figure 1, a corridor 88 separates the selenium-rich region I from the germanium-rich region II. Mitkova et al. mentions that no bulk glass formation occurs along the corridor 88 until the silver (Ag) concentration exceeds $y \geq 0.2$ and the two selenium-rich and germanium-rich regions I and II coalesce.

[0029] The study conducted by Mitkova et al. concluded that silver (Ag) acts as a “network modifier” for the glass compositions of the selenium-rich region I (Figure 1). In this region, silver (Ag) phase separates into an Ag_2Se -rich phase and a $\text{Ge}_{x}\text{Se}_{1-x}$, $\text{Ge}_{x}\text{Se}_{100-x}$ phase which has less Se than the starting $\text{Ge}_{x}\text{Se}_{1-x}$, $\text{Ge}_{x}\text{Se}_{100-x}$ material. In contrast, in the germanium-rich region II (Figure 1), silver (Ag) acts as a “network former” for glass compositions, forms part of the backbone and reduces the connectivity of the glass.

[0030] Referring back to Figure 1 and further analyzing the ternary phase diagram with glass forming regions for $(\text{Ge}_x\text{Se}_{1-x})_{1-y}\text{Ag}_y$, $(\text{Ge}_x\text{Se}_{100-x})_{100-y}\text{Ag}_y$ compounds, Applicant has discovered that the careful selection of the stoichiometry of a chalcogenide glass is directly correlated to the ability of the doped chalcogenide glass to maintain an amorphous state over a wide and continuous range of dopant metal concentrations and, therefore, to successfully function as a programmable memory cell.

[0032] According to the present invention, germanium selenide glass compositions capable of creating functional non-volatile memory devices require glass stoichiometries to fall in one of the following two ranges:

a first stoichiometric range R₁ including $\text{Ge}_{18}\text{Se}_{82}$ (with a maximum atomic percentage of Ag when doped of about 30% or less) continuously to $\text{Ge}_{28}\text{Se}_{72}$ (with a maximum atomic percentage of Ag when doped of about 20% or less) and which have the general formula $(\text{Ge}_x\text{Se}_{1-x})_{1-y_1}\text{Ag}_{y_1}$, $(\text{Ge}_{x_1}\text{Se}_{100-x_1})_{100-y_1}\text{Ag}_{y_1}$, wherein $18 \leq x_1 \leq 28$ and wherein y₁ represents the fit silver (Ag) atomic percentage which is the maximum amount which will keep the glass in the glass forming region. Typically, y₁ is less than or equal to that which approximately satisfies equation (1):

$$y_1 = 19 + 15 * \sin[0.217*x_1 + 3.23] \dots \dots \dots \quad (1)$$

or

a second stoichiometric range R₂ of doped chalcogenide glasses including Ge₃₉Se₆₁ (with a maximum atomic percentage of Ag when doped of about 20% or less) continuously to Ge₄₂Se₅₈ (with a maximum atomic percentage of Ag when doped of about 15% or less) and which have the general formula $(Ge_{x_2}Se_{1-x_2})_{1-y_2}Ag_{y_2}$ ($Ge_xSe_{100-x_2})_{100-y_2}Ag_{y_2}$, wherein $39 \leq x_2 \leq 42$ and wherein y₂ represents the fit silver (Ag) atomic percentage which is the maximum amount which will keep the glass in the glass forming region. Typically, y₁ is less than or equal to that which approximately satisfies equation (2):

$$y_2 = 21 - 11.5 * \exp[-(\ln(x_2/44.4) / (0.84)^2)]. \dots \dots \dots \quad (2)$$

[0045] Referring now to Figure 5, incorporation of silver into the Ge₂₃Se₇₇ glass 17 may be accomplished by photodoping, that is depositing a thin layer 18 comprising silver, preferably predominantly elemental silver, over the Ge₂₃Se₇₇ glass 17 and then "driving" the silver atoms within the Ge₂₃Se₇₇ glass by using light (Figure 6), or by co-sputtering with Ag, Ge and Se, or Ag and a Ge₂₃Se₇₇ target, or Ag₂Se and Ge_xSe_{1-x} Ge_xSe_{100-x} . The thickness of the layer 18 comprising silver is selected so that, when the silver is subsequently diffused into the germanium selenide glass layer 17, the atomic percentage of Ag in resulting silver-doped chalcogenide glass 20 (Figure 7) will allow such glass to fall within a glass forming region R₁ or R₂.